NSG 5120

NORTH CAROLINA CENTRAL UNIVERSITY
DURHAM, NORTH CAROLINA 27707

DEPARTMENT OF PHYSICS

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Final Report

Grant No. NSG 5120

OPTICALLY PUMPED SUBMILLIMETER-WAVES AND APPLICATIONS

(NASA-CR-168769) OPTICALLY PUMPED SUBMILLIMETER-WAVES AND APPLICATIONS Final Report (North Carolina Central Univ., Durham.) 14 p HC A02/MF A01 CSCL 20E

N82-22492

Unclas
G3/36 09575

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Prepared for

National Aeronautics and Space Administration
Goddard Spaceflight Center
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ABSTRACT

Rapid development of optically pumped lasers has shown the potential to be used as a source for a high-resolution spectrometer. In this connection, a compact, stable FIR laser has been designed, fabricated, and assembled in this laboratory, integrating both the pump laser and the FIR cavity in the same mechanical structure for its improved (both thermal and mechanical) stability and mobility. Performance of the mixer structure which has been designed and constructed in this laboratory for the evaluation of the Schottky diodes is found to be satisfactory. The feasibility of generating tunable sideband for molecular spectroscopy studies has been demonstrated.

FINAL REPORT

The measurement of trace gas species in the stratosphere by means of spectroscopic observations in the submillimeter (SMM) portion of the spectrum is currently a topic of considerable interest. Researchers at NASA Goddard Space Flight Center have successfully demonstrated a submillimeter heterodyne radiometer based on an optically-pumped molecular laser (OPML) for the local oscillator and a quasi-optical Schottky-diode mixer. Field studies employing such an instrument will require knowledge of the molecular spectra of the target gas based on precise laboratory data. For many molecular species of interest, the needed data is missing or incomplete due largely to the inadequacies of conventional spectrometers. The goal of this project has been the development of a high resolution spectrometer which could acquire the necessary laboratory data. This goal has been substantially completed.

The approach taken here is to employ a quasi-optical mixer to combine a microwave signal with the fixed frequency output of an OPML. The resulting tunable sidebands then serve as a suitable source for spectroscopy. The critical elements in this method are the laser local oscillator and the quasi-optical mixer.

A stable local oscillator has been designed and constructed (Figure 1). This optically pumped, molecular laser which consists of a unified CO_2 pump-SMM cavity combination produces an output with good stability and a near-

Gaussian spatial mode profile (Figure 2). It has proven to be a satisfactory local oscillator for submillimeter studies.

The quasi-optical mixer structure which was developed is shown in Figure 3.[1] This design differs from those reported by others, chiefly in the absence of a ground plane and the maintenance of an approximate symmetry about the diode.[2] This results in an antenna pattern (Figure 4) which has two principal lobes. This is well suited to implementation of a modulator where the carrier is focused into one lobe and the modulated carrier re-radiated in the opposite lobe. Currently, the Schottky diodes utilized in this structure are high frequency devices developed at University College in Cork, Ireland.[3] This combination has yielded excellent performance both as a video detector and as a mixer. The characteteistics and results obtained are summarized in Table 1. When this mixer is employed to combine the laser local oscillator with a 4 GHz microwave signal, approximately 0.1% of the LO power appears in each sideband. With 1 mW LO output, this generates 1 μw of tunable sideband power. This is more than adequate power for spectroscopic studies, especially when a second mixer is employed as a sensitive heterodyne receiver. The mixer performance has been demonstrated to date from audio frequencies up to 4 GHz and extension to 8 GHz is in progress.[4] The performance as a function of applied microwave power is shown in Figure 5. It can be seen that very little microwave drive is required to saturate these diodes.

A high-resolution spectrometer system based on this sideband generation technique has been assembled as shown in Figure 6. The modulated radiation from the first mixer is focused into a one-meter cell containing the sample gas. The radiation exiting the cell is demodulated by a second mixer, then amplified and detected by conventional low-noise microwave

equipment. Absorption lines in the sample are detected as dips in the output when the sideband frequency is tuned by changing the frequency of the microwave modulation. Evaluation of this spectrometer system with SO_2 sample gas is now in progress. Application of the system to study gases of interest in the stratosphere will then commence.

FOOTNOTES

1. Dutta, J.M. and C.R. Jones, Bull. Am. Phys. Soc., Jan., 1979.

2. Fetterman, H.R., et.al., 1973, App. Phys. Lett., V33, No. 2, pp. 151-154.

3. Work reported here was performed with diodes generously supplied by Dr. W. M. Kelly, University College, Cork, Ireland. They have a cut-off frequency of ~3000 GHz.

4. Jones, C.R., H. Dave', and J.M. Dutta, Conf. Digest, Sixth Int. Conf. on IR and MM Waves, Dec., 1981.

PARTICIPATING SCIENTIFIC PERSONNEL

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TABLE 1

ANTENNA CHARACTERISTICS

Length = 2λ

Reflector = 90° corner

Principal Forward Lobe = 54°

Principal Back Lobe = 58°

DIODE CHARACTERISTICS

Diameter = 1 micrometer

Capacitance = 5.5 femtofarads

Series Resistance = 12 Ohms

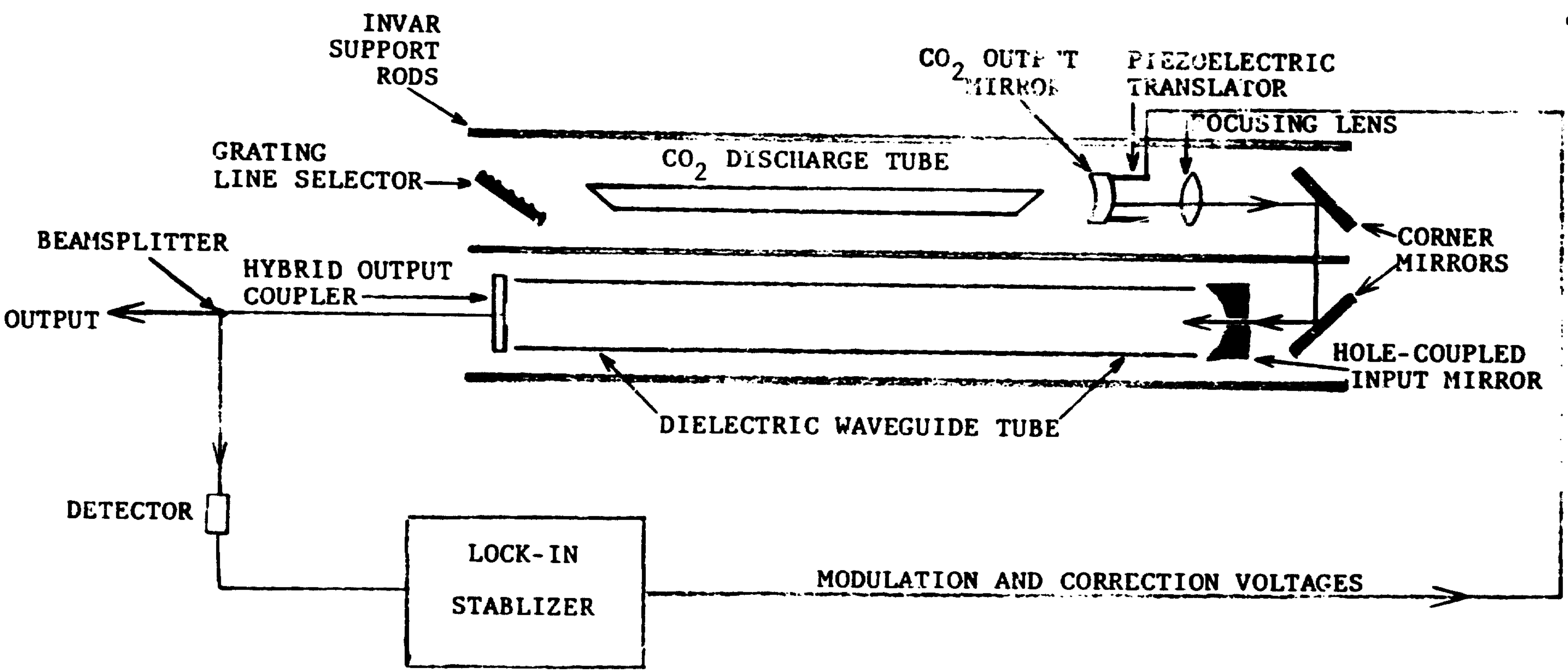
RESULTS OBTAINED

Video Responsivity ≈ 100 V/W

Modulation Percentage ≈ 1.5%

Sideband Conversion Efficiency ≈ 0.1%

FIGURE 1 OPTICALLY-PUMPED SUBMILLIMETER LASER SYSTEM



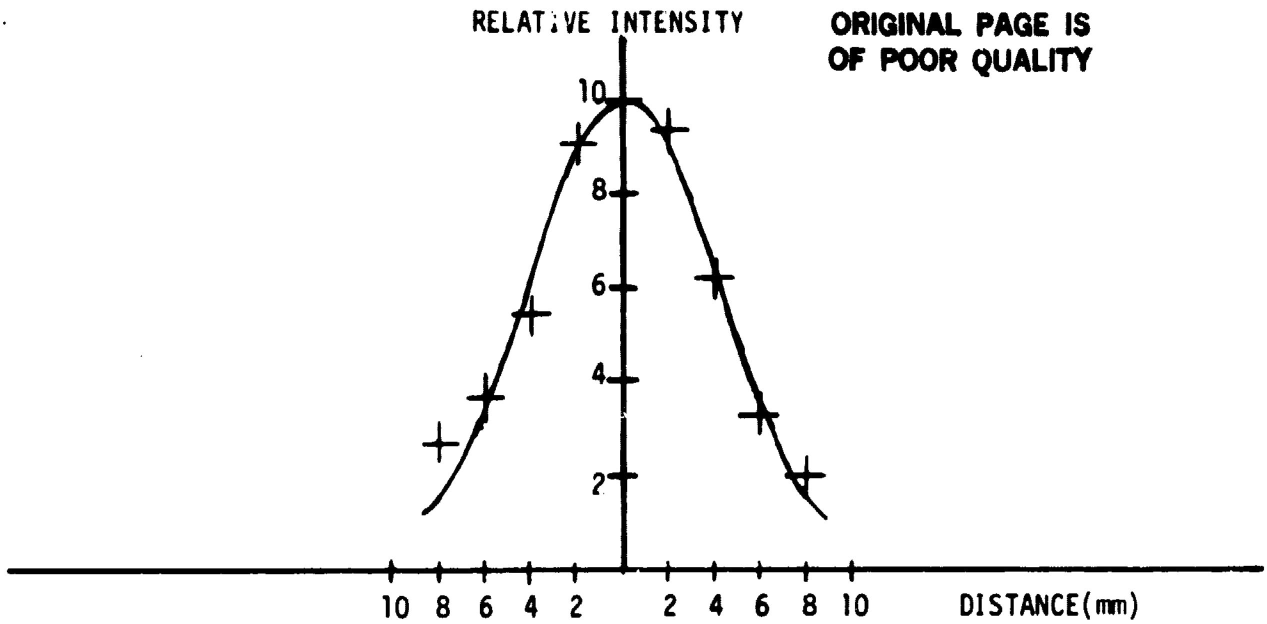


FIGURE 2A SUBMILLIMETER OUTPUT PROFILE

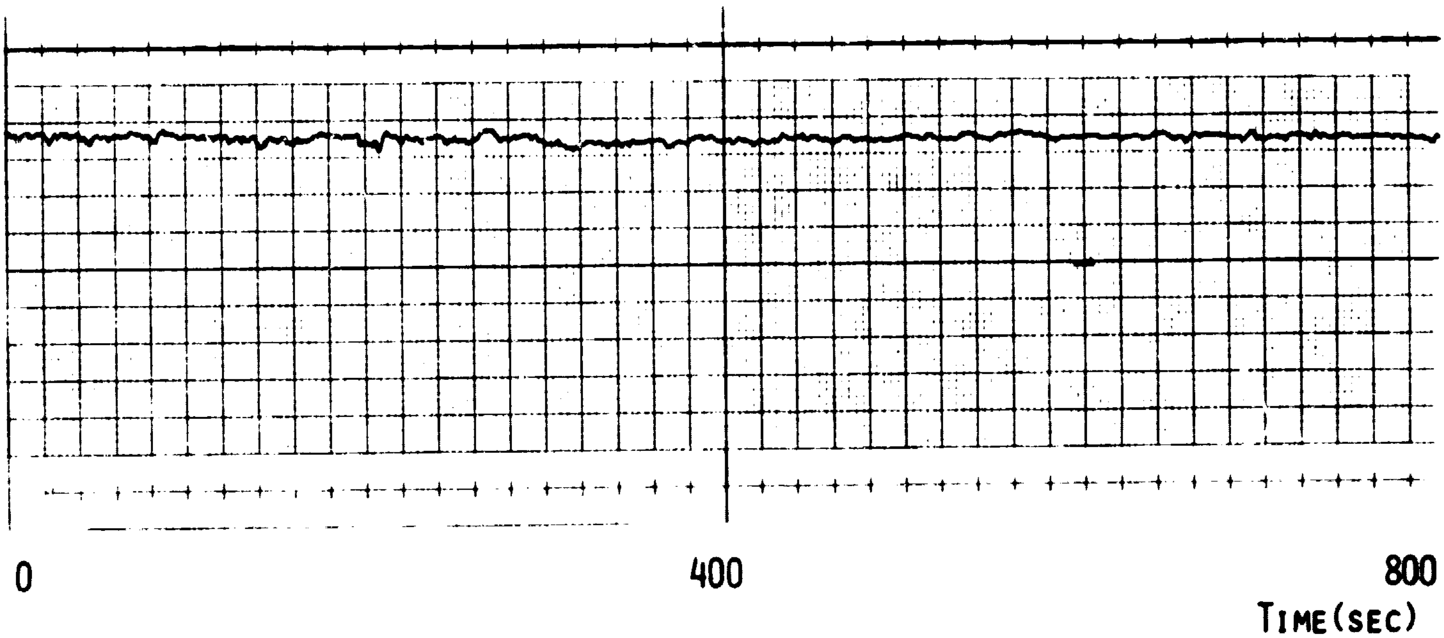


FIGURE 2B SUBMILLIMETER OUTPUT STABILITY

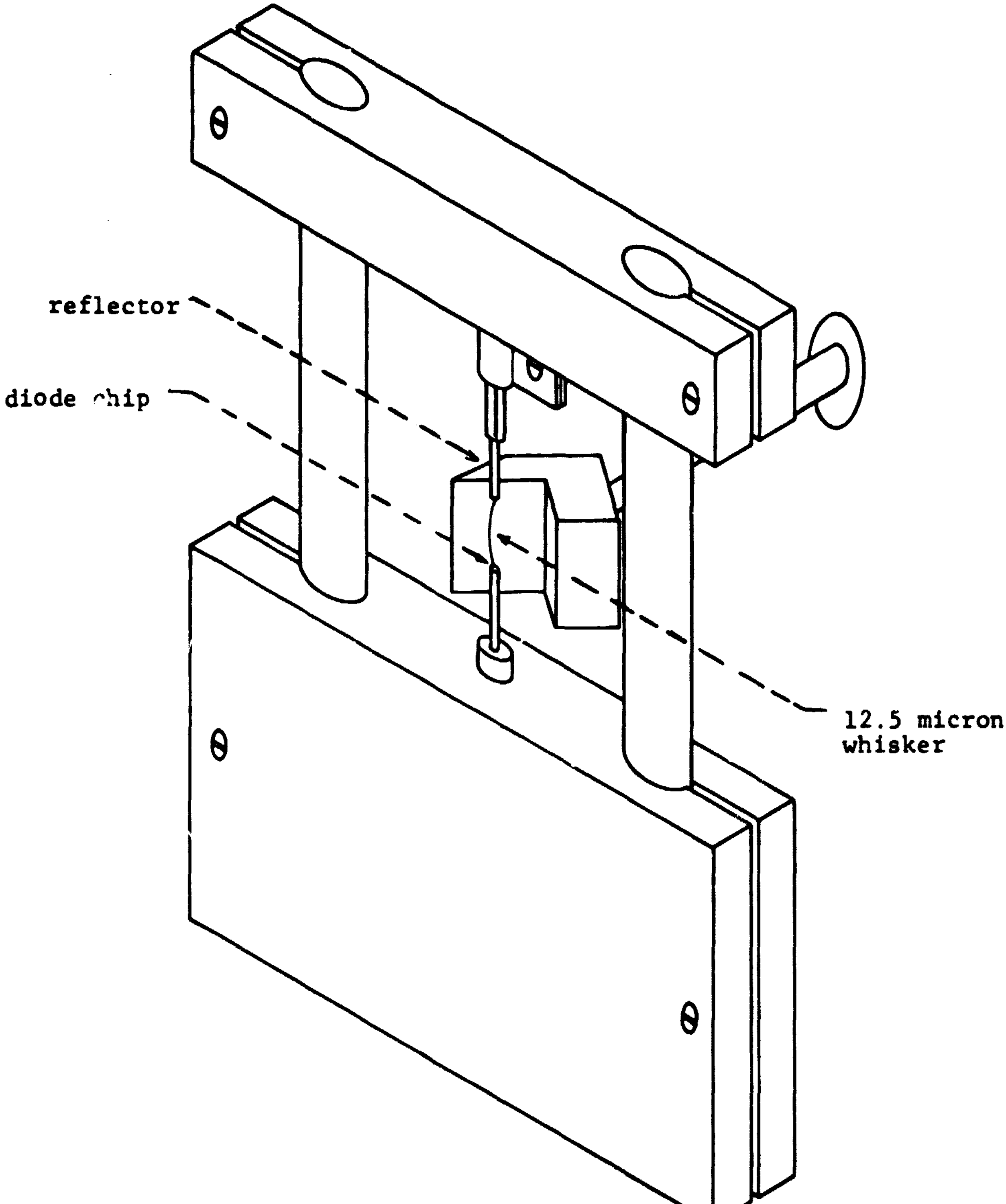
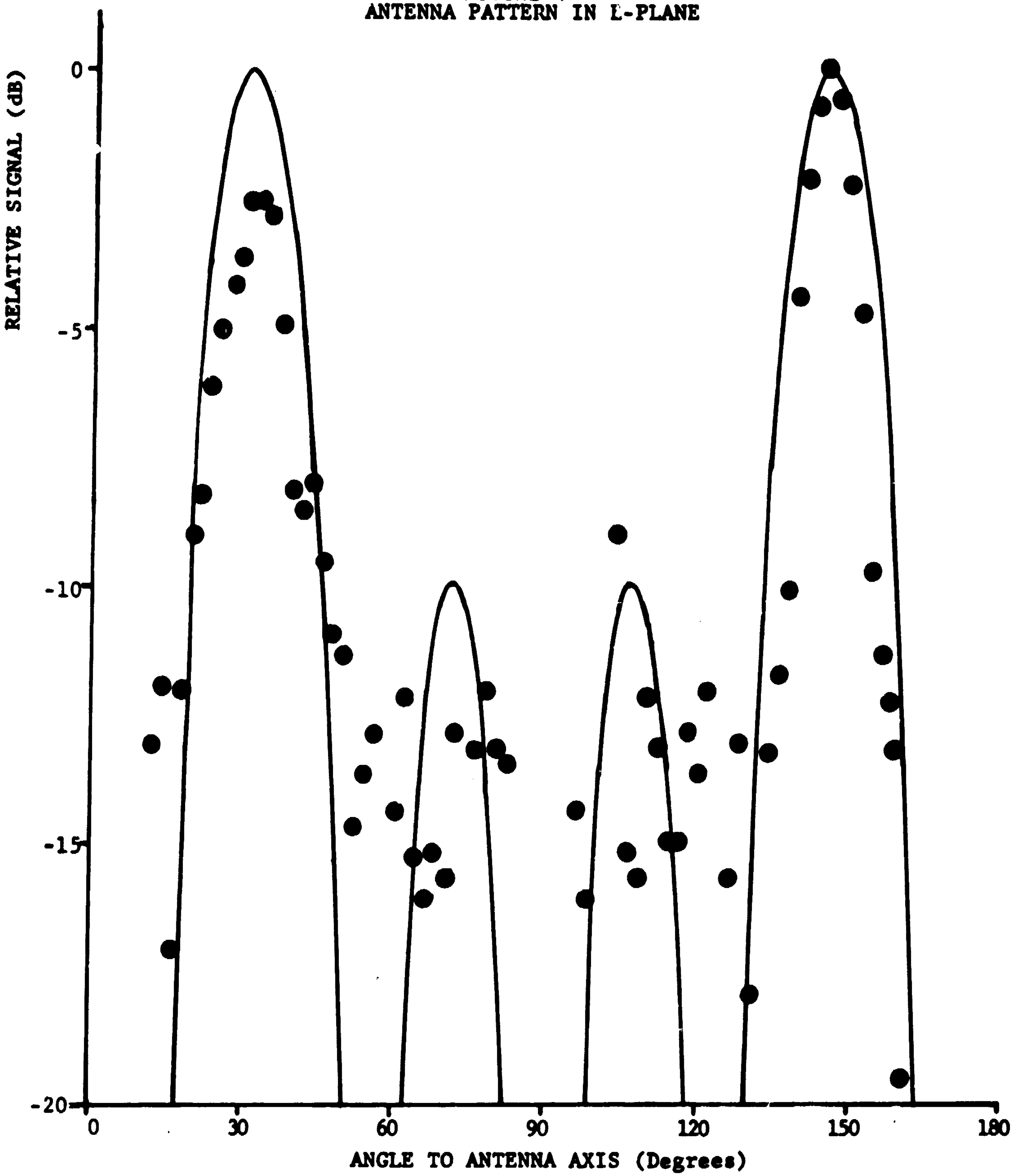


FIGURE 3- QUASI-OPTICAL DIODE MIXER

FIGURE 4
ANTENNA PATTERN IN E-PLANE



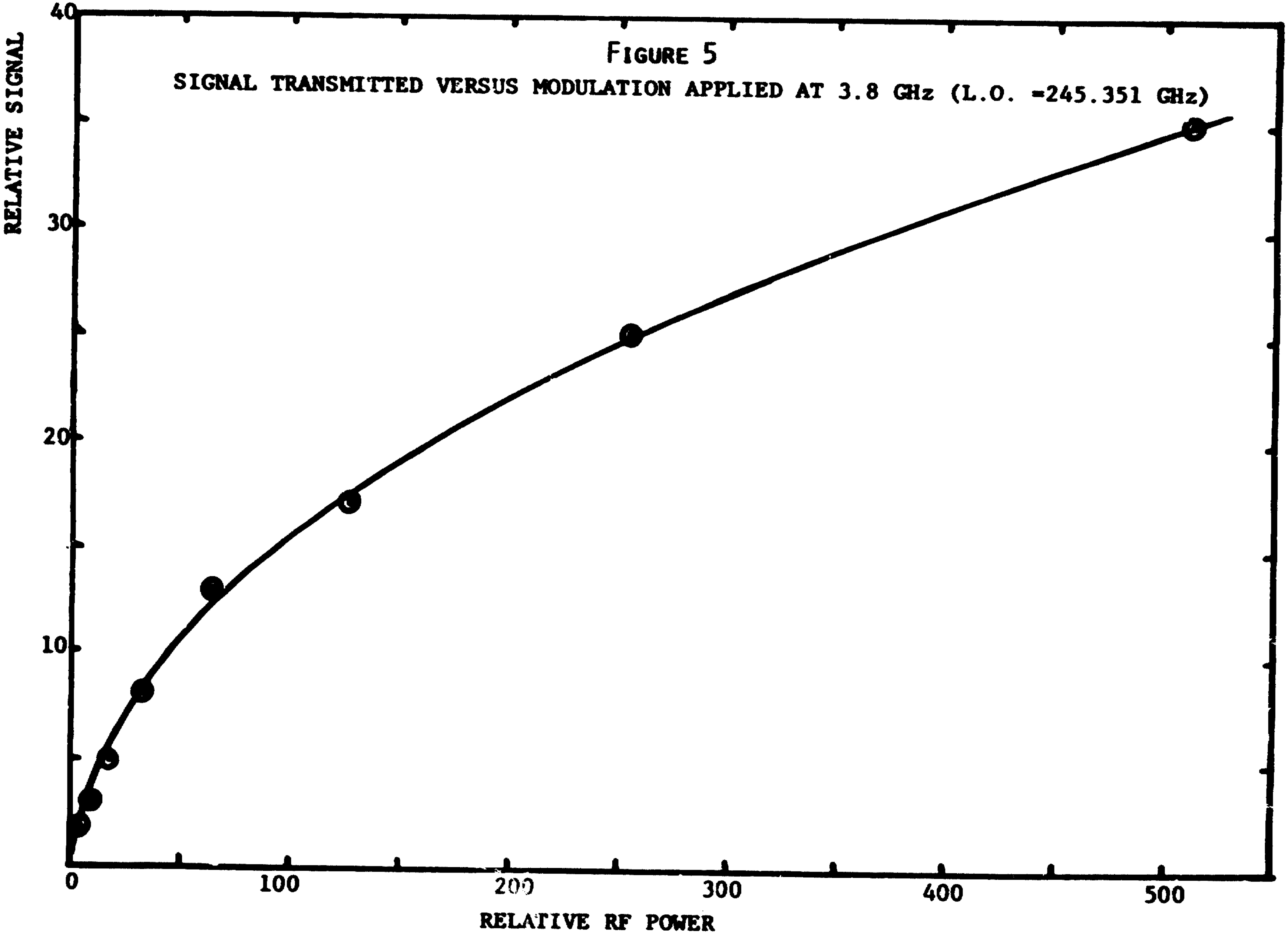


FIGURE 5

SIGNAL TRANSMITTED VERSUS MODULATION APPLIED AT 3.8 GHz (L.O. =245.351 GHz)

Figure 6

SUBMILLIMETER SPECTROMETER